Protoplanetary Disks in the Nearest Star-Forming Cloud: Mid-Infrared Imaging and Optical Spectroscopy of MBM 12 Members

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ABSTRACT

The recent identification of several groups of young stars within 100 parsecs of the Sun has generated widespread interest. Given their proximity and possible age differences, these systems are ideally suited for detailed studies of star and planet formation. Here we report on the first investigation of protoplanetary disks in one such group, the high-latitude cloud MBM 12 at a distance of ∼65 pc. We present mid-infrared observations of the eight candidate pre-main-sequence (PMS) members and the two main-sequence (MS) stars in the same line-of-sight which may or may not be associated with the group. We have also derived Hα and Li line widths from medium-resolution optical spectra. We report the discovery of significant mid-infrared excess from six PMS stars –LkHα 262, LkHα 263, LkHα 264, E02553+2018, RXJ0258.3+1947 and S18 –presumably due to optically thick circumstellar disks. Our flux measurements for the other two PMS stars and the two MS stars are consistent with photospheric emission, allowing us to rule out dusty inner disks. The disks we have found in MBM 12 represent the nearest known sample of very young protoplanetary systems, and thus are prime targets for high-resolution imaging at infrared and millimeter wavelengths.

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1. Introduction

Several groups of young stars within 100 parsecs of the Sun have recently received much attention as suitable laboratories for detailed studies of star and planet formation. Many of these groups, such as the TW Hydrae Association at ∼55 pc (Kastner et al. 1997) and the η Chamaeleontis cluster at ∼97 pc (Mamajek, Lawson & Feigelson 1999), are far from any obvious parent molecular clouds. Thus, their nature, origin, and age are still matters of debate. The most likely explanation for their isolation is that these stars are somewhat older than the T Tauri stars found in well-known star-forming regions (e.g., Taurus-Auriga) and that their parent clouds have dispersed rather quickly.

However, one nearby young star group *does* appear to be associated with the high-latitude cloud MBM 12 (Magnani, Blitz, & Mundy 1985). At a distance of ∼65 pc, MBM 12 (=L1457) is the nearest known molecular cloud (Hobbs, Blitz, & Magnani 1986; Hearty et al. 2000b). Based on *ROSAT* detections and ground-based follow-up optical spectroscopy, Hearty et al. (2000a) have identified 8 late-type young stars in MBM12 and two other main-sequence stars in the same line-of-sight which may or may not be related. Recent surveys suggest that additinal low-mass stars may be present in this region (Wolk et al. 2000).

This intermediate-mass molecular cloud may be representative of how groups like TW Hydrae and η Cha appeared at an earlier epoch, i.e., at ∼1 Myr. Since MBM 12, which contains only ∼30-100 $M_{\odot}$ of gas, does not appear to be gravitationally bound, it may be breaking up on a timescale comparable to the sound-crossing time. Thus, in a few million years, the young stars in MBM12 may appear to be isolated objects, not associated with any molecular material –similar to the other nearby "dispersed" groups.

Whether MBM12 disperses in a few million years or not, it constitutes an excellent sample of extremely nearby young stars for investigating the earliest stages of protoplanetary disk systems. In particular, comparison of disk properties and statistics between MBM12, TW Hydrae Association (Jayawardhana et al. 1998, 1999a, 1999b) and η Cha cluster could provide interesting constraints on the diversity and evolution of circumstellar disks (Jayawardhana 2000b). Furthermore, if newborn giant planets or brown dwarfs exist around MBM 12 stars, it may be possible to image those very-low-mass companions directly using adaptive optics on large ground-based telescopes (Jayawardhana 2000a).

Here we present the results of the first investigation of protoplanetary disks in the MBM 12 group, using mid-infrared imaging and optical spectroscopy.

2. Data

2.1. K-band photometry

For 9 of the 10 sources in our sample, we extracted K-band (2.17μm) photometry from the 2-Micron All-Sky Survey (2MASS) point-source catalog. In all cases, the 2MASS counterparts were found within 2" of the nominal position and have photometric uncertainties less than 0.1 mag. Since the 2MASS catalog does not contain photometry for HD 17332, we have estimated its K from V=6.87, reported in SIMBAD, and standard $V-K$ color (Kenyon & Hartmann 1995) for G0V spectral type.

2.2. L-band imaging

We obtained L-band images of all 10 stars in the sample at the United Kingdom InfraRed Telescope (UKIRT) on Mauna Kea, Hawaii, on February 15 and 16, 2000 (UT). We used IRCAM/TUFTI, a 1-5μm camera with a 256×256 InSb detector. The plate scale is 0.081"/pix, resulting in a 20.8" field of view. The standard stars HD 40335 (m_L=6.43) and HD 106965 (m_L=7.30) were used for flux calibration.

2.3. N-band imaging

We observed the targets in the N-band (λ_0 = 10.8μm) using the OSCIR mid-infrared instrument on the 10-meter Keck II telescope on November 19 and 21, 1999 (UT). OSCIR is a mid-infrared imager/spectrometer built at the University of Florida[1], using a 128×128 Si:As Blocked Impurity Band (BIB) detector developed by Boeing. On Keck II, OSCIR has a plate scale of 0.062"/pixel, providing a 7.9"×7.9" field of view. Our observations were made using the standard chop/nod technique with a chop frequency of 4 Hz and a throw of 8" in declination. Flux calibration was performed using the mid-infrared standards α Ari (m_N=-0.80) and α CMi (m_N=-0.76).

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[1]Additional information on OSCIR is available on the Internet at www.astro.ufl.edu/iag/.

2.4. Optical spectroscopy

We observed all 10 stars using the Ritchey-Chretien Focus Spectrograph on the Kitt Peak National Observatory 4-meter telescope on September 6 and 7, 2000 (UT). The BL 450 grating at second order with 632 lines/mm grating and 1.7" slit yielded vignetted coverage of the 6030-7500 Å region at a resolution of 1.4 Å/2 pixels. The resulting spectra are shown in Figure 1. The equivalent line widths for Hα and Li 6708 Å(unvignetted), listed in Table 1, were derived by fitting a Voigt profile to the lines. This method tends to give slightly ($\sim$10%) smaller values for Hα than a simple integration of the area under the curve, because it is hard to define the line edges; the effect for lithium is minimal.

3. Results

In Table 1, we present K, L and N-band magnitudes for the entire sample, as well as $K-L$ and $K-N$ colors. (The photometric error was estimated by monitoring the variation of standard star fluxes throughout the night and by comparing the results among several standards.) For all late-type stars, the photospheric $K-L$ and $K-N \approx 0$ (Kenyon & Hartmann 1995). Thus, excess emission at mid-infrared wavelengths is an excellent diagnostic of dusty circumstellar material in close proximity to young stars (e.g., Jayawardhana et al. 1999b). In particular, $K-L \gtrsim$ 0.3-0.5 mag (Kenyon & Hartmann 1990; Edwards, Ray & Mundt 1993) and $K-N \gtrsim 1.2$ mag (Skrutskie et al. 1990) indicate optically thick inner disks and correlate with characteristic T Tauri spectral line activity. In the case of MBM 12 stars, the K magnitude is not an exact measure of photospheric emission because it may be slightly affected by extinction and also include a contribution from thermal radiation of the inner disk. However, corrections of both effects will only increase the measured $K-L$ and $K-N$ color excesses; thus, our disk detection criterion is a conservative one.

The $K-L$ and $K-N$ colors in Table 1 unambiguosly show significant mid-infrared excess from six PMS stars –LkHα 262, LkHα 263, LkHα 264, E02553+2018, RXJ0258.3+1947 and S18. In all six cases, the colors are consistent with thermal emission from optically thick inner disks. The other two PMS stars –RXJ0255.4+2005 and RXJ0306.5+1921– do not show a measurable mid-infrared excess within the photometric errors, allowing us to rule out such disks. HD 17332 and RXJ0255.3+1915, the two main-sequence stars in the line-of-sight to MBM 12, also lack evidence of warm circumstellar material.

Figure 1 shows the optical spectra for all 10 stars in the sample. Three of the objects –LkHα 262, LkHα 263 and E02553+2018– clearly show two components in the Hα line, and are probably close binaries. LkHα 264 also appears to have a blended Hα line, but the two components are not resolved well enough in our medium-resolution spectra to measure their line widths separately.

Table 2 lists the Hα and Li I 6708 Å line widths of single-line objects while Table 3 gives the line widths of blue and red Hα components as well as Li I 6708 Å for the double-line sources. The spectral types given in Table 2 and 3 are based on Hearty et al. (2000a).

An Hα equivalent width greater than 10 Å is generally considered to be the accretion signature of a classical T Tauri star with a circumstellar disk (Herbig & Bell 1988). A smaller equivalent width signifies chromospheric activity, but no accretion. Therefore, mid-infrared excess we measure should be correlated with large Hα line widths. Indeed, this generally holds true for MBM 12 stars with one notable exception: E02553+2018. This object, likely a binary as discussed in Section 4, has large mid-infrared excesses ($K-L$=1.06, $K-N$=2.45) but weak Hα emission in both blue (-1.44 Å) and red (-2.64 Å) components.

4. Discussion

We have detected mid-infrared emission from optically thick disks around 6 of the 8 known PMS candidates associated with MBM 12. Our results confirm, and augment, the evidence for protoplanetary material associated with a significant fraction of late-type PMS stars. The exact fraction of stars with disks appears to vary from one star-forming region to another. For example, in their Taurus-Auriga sample of stars younger than 3 million years (Myr), Skrutskie et al (1990) found that roughly 50% showed mid-infrared excess consistent with optically thick disks (also see Wolk & Walter 1996). On the other hand, using L-band observations, Lada et al. (2000) estimated that 80%-85% of Trapezium stars harbor circumstellar disks, confirming earlier suggestions of a high disk fraction for this $\sim$1-Myr-old cluster in Orion. The disk fraction we find in MBM 12 –75%– falls in the middle of the range reported for other star-forming regions. Due to uncertainties in the age estimates of young stellar samples, it is not yet clear whether the observed differences in disk frequency are due to rapid evolution or environment.

However, it is interesting to compare the disk properties of MBM 12 to those of the TW Hydrae Association and the η Cha cluster. The two latter groups appear to be measurably older; age estimates for both groups, using a variety of techniques, yield $\sim$10 Myr (Jayawardhana et al. 1999b and references therein; Mamajek, Lawson & Feigelson 1999). Our previous work has shown that many of the TW Hya stars have little or no disk emission at 10μm (Jayawardhana et al. 1999b). Even among the five stellar systems with 10μm excesses, most show some evidence of inner disk evolution. The disk around the A0V star HR 4796A has an $r \approx 50$ AU central hole in mid-infrared images. The SEDs of HD 98800 and Hen 3-600A also suggest possible inner disk holes. The modest excess we detected from CD -33°7795 could well be due to a faint companion. Only TW Hya itself appears to harbor an optically thick, actively accreting disk of the kind observed in $\sim$1-Myr-old classical T Tauri stars; it is the only one with a large Hα equivalent width (-220 Å). Among the 12 known members of the η Cha cluster, only 2 have Hα equivalent widths

larger than 10 Å (Mamajek, Lawson & Feigelson 1999), suggestive of disk accretion. Clearly, the frequency of classical T Tauri disk systems is significantly higher in MBM 12 ($\sim$75%) in comparison to TW Hya Association ($\lesssim$20%) and η Cha cluster ($\lesssim$20%). These disk fractions, albeit among small samples of stars, suggest that few inner disks survive beyond 10 Myr. This timescale may be closely related to the planet formation process (Jayawardhana 2000b).

Our medium-resolution spectra have revealed that at least three of the MBM 12 sources –LkHα 262, LkHα 263, and E02553+2018– could be close binary systems, although wind absorption cannot be ruled out as the cause of the double-peaked line profiles. If binaries, it may be possible to resolve them with adaptive optics instruments on large ground-based telescopes. Given the likely small physical separation of these binaries, follow-up astrometric observations can yield direct dynamical masses relatively quickly. Therefore, MBM 12 binary systems may prove to be useful laboratories for testing evolutionary models of low-mass stars. It may also be worth searching for cirumbinary disks in these systems. The case of E02553+2018 is puzzling, because it has a large mid-infrared excess but weak Hα line emission. We tentatively suggest that E02553+2018 is a candidate for harboring circumbinary dust.

The Hα emission line of LkHα 264 also consists of two components. However, Lago & Gameiro (1998), who performed time-series analysis of high-resolution profiles, suggest that the Hα line of that star is produced in two distinct regions –an inner, dense region and an outer, more extended region. These authors also found the blue component of the line to be highly variable, which may account for the smaller line width we measure ($\sim$18 Å) when compared to previously published values ($\sim$60-100 Å ; Hearty et al. 2000a, Lago & Gameiro 1998).

The disks we have found around MBM 12 stars (together with TW Hya) may represent the nearest known sample of optically thick, actively accreting circumstellar disks. Thus, they are ideal for detailed studies of the early stages of protoplanetary systems. Their proximity offers a spatial resolution twice that of other nearby stellar nurseries such as Taurus-Auriga and Chamaeleon. In particular, molecular line and continuum observations using (sub)millimeter interferometers will allow us to probe the gaseous component and the outer disks of these systems. MBM 12 is also a suitable region for sensitive searches of brown dwarfs and massive young planets.

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TABLE 1

INFRARED PHOTOMETRY AND COLOR EXCESS[a]

Name	K	L	N	$K-L$	$K-N$
Pre-main-sequence stars					
RXJ0255.4+2005	8.99	8.91	8.84	0.08	0.15
LkHα262	9.66	8.84	7.02	0.82	2.64
LkHα263	9.52	8.97	7.07	0.55	2.45
LkHα264	8.90	8.13	5.15	0.77	3.75
E02553+2018	8.11	7.05	5.66	1.06	2.45
RXJ0258.3+1947	10.73	10.43	8.58	0.30	2.15
S18	9.56	8.66	7.81	0.90	1.75
RXJ0306.5+1921	9.72	9.75	9.70	-0.03	0.02
Main-sequence stars					
HD17332[b]	5.46	5.36	5.47	0.10	-0.01
RXJ0255.3+1915	9.02	8.99	9.06	0.03	-0.04

[a] The errors in K, L, N photometry are ± 0.1 mag.

[b] HD 17332 is a known binary. L and N reported in the Table is the total for the binary so that a comparison can be made with K. For HD17332A, we measure L=5.92, N=5.97 and for HD17332B, we find L=6.34, N=6.56.

TABLE 2
EQUIVALENT WIDTHS OF Hα AND Li I 6708Å LINES
FOR STARS WITH ONE COMPONENT

Name	Spectral Type	W(Hα)(Å)[a]	W(Li)(Å)	N(obs)[b]
RXJ0255.4+2005	K6	-0.927 ± 0.08	0.31 ± 0.03	5
LkHα264[c]	K5	-17.73 ± 0.19	0.41 ± 0.01	2
RXJ0258.3+1947	M5	-33.79 ± 0.58	0.42 ± 0.04	2
S18	M3	-69.22 ± 1.25	0.35 ± 0.01	2
RXJ0306.5+1921	K1	0.31 ± 0.01	0.22 ± 0.02	2
HD17332A	G0	1.73 ± 0.02	0.16 ± 0.01	2
HD17332B	G5	2.45 ± 0.03	0.14 ± 0.01	2
RXJ0255.3+1915	F9	2.69 ± 0.01	0.13 ± 0.01	3

[a]A negative sign denotes emission.

[b]Number of observations.

[c]Possibly two lines, but unresolved.

TABLE 3
EQUIVALENT WIDTHS OF Hα AND Li I 6708Å LINES
FOR STARS WITH TWO COMPONENTS

Name	Spectral Type	W(Blue Hα)(Å)[a]	W(Red Hα)(Å)[a]	W(Li)(Å)	N(obs)[b]
LkHα262	M0	-13.10 ± 0.25	-26.64 ± 1.80	0.51 ± 0.07	3
LkHα263	M4	-8.72 ± 0.36	-5.02 ± 0.45	0.39 ± 0.05	3
E02553+2018	K4	-1.44 ± 0.10	-2.64 ± 0.13	0.39 ± 0.01	3

[a]A negative sign denotes emission.

[b]Number of observations.

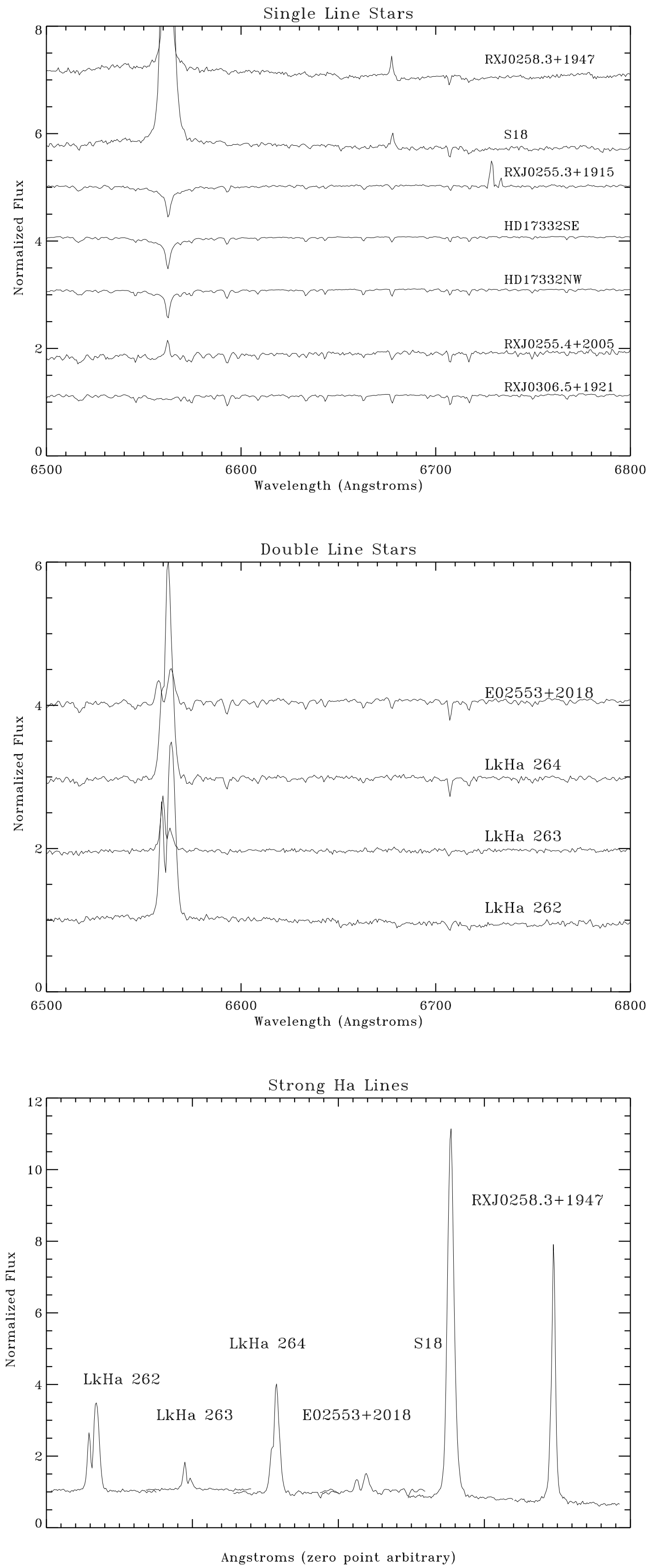

Fig. 1.— The optical spectra of single-line (*top panel*) and double-line (*center panel*) systems. Bottom panel shows detail of the Hα lines of strong emitters.